REDUCTION OF ENERGIZATION TRANSIENTS IN A THREE PHASE Y-CONNECTED LOAD

BACKGROUND OF THE INVENTION

5 ### 1. Field of Invention

This invention relates to reduction of energization transients in three phase power systems and more particularly to a method of reducing energization transients in a Y-connected load and to an energization transient limited three phase AC power system apparatus.

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2. Description of Related Art

Transformers, reactors and capacitors are common equipment in utility power systems. When such equipment is energized by a power system it normally produces energization transients such as voltage and/or current surges. These transients are 15 often the result of inrush currents into the load being energized. Energization transients are often reflected back into the power system which can disrupt the operation of power quality sensitive electrical loads such as computers and medical equipment connected to the system. Power quality sensitive electronics are in increasing use and thus control of energization transients has become an important 20 concern to the power industry.

Over the past twenty years, two main methods have evolved to limit inrush currents as a way of reducing energization transients. A first method involves pre-insertion of damping resistors or inductors. This involves insertion of an impedance such as a 25 resistor and/or inductor in series with each leg of the load. Each resistor and/or inductor is then bypassed after the leg has been energized and has reached a steady state condition. The use of a resistor tends to increase the damping of the overall circuit, resulting in faster disappearance of transients. The main disadvantage of this method is the need for a separate bypass circuit breaker and resistor for each phase. 30 Systems of this type are described in US patents 6,018,473, 6,218,652, 4,695,918, for example.

A second method involves precisely controlling the closing instant of the switches or breakers connecting the load to the power system such that each breaker is closed at precisely the instant when the system voltage or current, depending on the load, in the corresponding phase is zero. If the load is capacitive, the breaker associated with each phase is closed when the voltage of the corresponding phase is zero. If the load is inductive, the breaker is closed when the voltage is maximum and current is zero. With the advancement of microprocessor technology, this method has become technically feasible and has gained acceptance in industry. This method however requires specially designed circuit breakers that have consistent mechanical operation characteristics over a wide range of installation and temperature conditions. The tolerance for error on closing time is very small (less than 2 to 5 milliseconds). The reliability of such a scheme and the sophistication involved makes it unattractive for general applications. This technology and its variations are described in US patents 5,838,077, 6,523,654, for example.

A variation of the first method above, for use with transformer loads involves the connection of a resistor between the transformer neutral and ground. This scheme has been described in B. Holmgrem, R. S. Jenkins and J. Rinbrugent, "Transformer inrush current," *CIGRE Proc. Of the 22nd session*, vol. 1, 12-03, pp. 1-13, 1968 and R. Yacamini and A. Abu-Nasser, "The calculation of inrush current in three-phase transformers," *IEE Proc.-Electr. Power Appl.*, vol. 133, no. 1, pp. 31-40, Jan. 1986. Both papers describe concurrent energization of all three legs and both concluded that the neutral resistor has no effect on limiting inrush currents.

Another attempt to simplify the first method is described in US patent 6,337,802 and involves the use of one series resistor switched into different phases of the load so that the effect of three resistors is at least partially realized. This method appears to be suited for low or medium voltage converter applications and could be more expensive than the basic series resistor method if applied to high voltage power systems as it requires several additional switches.

The present invention addresses the above problems.

SUMMARY OF THE INVENTION

5   In accordance with one aspect of the invention, there is provided a method of reducing energization transients in a three phase Y-connected load having legs A, B and C associated with corresponding phases of a three-phase AC power system. The method involves energizing respective legs of the load in an order determined by a energization sequence dependent upon a type of the load. The energization

10   sequence defines first, second and third legs of the legs A, B and C to be energized. The method also involves providing a conduction path for current to flow between a neutral point of the Y-connected load to ground through a transient-limiting impedance while the first, second and third legs are being energized. The transient limiting impedance has an impedance value selected such that after the first leg is energized,

15   an energization transient produced on energizing the second leg and an energization transient produced on energizing the third leg are both approximately minimized.

       The energization transient may be current or voltage.

20   The method may involve selecting the impedance value of the transient-limiting impedance such that the energization transient produced on energizing the second leg may be approximately equal to the energization transient produced on energizing the third leg.

25   The impedance value of the transient-limiting impedance may be selected such that the impedance value of the transient-limiting impedance may be approximately equal to an impedance value at which a first curve depicting transient magnitude vs. transient-limiting impedance for the second leg intersects with a second curve depicting transient magnitude vs. transient-limiting impedance for the third leg.

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Energizing may involve closing first, second and third switches associated with respective legs of the load. The switches may include circuit breakers.

The transient-limiting impedance may be selected such that when the first and second legs are energized, a steady state open circuit voltage across the third switch is approximately equal to a steady state open circuit voltage across the second switch when only the first leg is energized.

The transient-limiting impedance may be selected to cause a minimum steady state open circuit voltage to appear across the third switch when the first and second legs are energized and to cause the minimum steady state open circuit voltage to appear across the second switch when only the first leg is energized.

The transient-limiting impedance may include at least one of a resistive component and a reactive component.

The transient-limiting impedance may be selected as a function of an open circuit reactance of the Y-connected load.

The Y-connected load may be a predominantly inductive load type and the energization sequence may cause leg A to be the first leg to be energized, leg B to be the second leg energized and leg C to be the third leg energized.

The Y-connected load may include transformer having a three-limb core structure.

The Y-connected load may include a transformer having a delta-connected secondary winding.

The transient-limiting impedance may be predominantly resistive.

The transient-limiting impedance may include a resistive component having a resistance of approximately 0.085Xopen, where Xopen is a open circuit reactance of the Y-connected load.

5   The Y-connected load may be a predominantly capacitive load type and the energization sequence may cause the first leg to be energized to be leg A, the second leg to be energized leg C and the third leg to be energized leg B.

The transient-limiting impedance may include a resistive component and an inductive
10   reactive component in series. The resistive component may have a resistance of approximately 0.085Xopen, where Xopen is an open circuit reactance of the Y-connected load and the inductive reactive component may have a reactance of approximately Xopen/3.

15   The second leg may be energized a period of time after the first leg is energized and the third leg may be energized the period of time after the second leg is energized. The period of time may be greater than or equal to a time period associated with approximately one cycle of an AC waveform associated with the three phase power system. The period of time may be greater than or equal to approximately 0.01
20   seconds. The period of time may be between approximately 0.01 seconds and 1 second. In general, the period of time can be as short as several cycles or as long as several seconds. The period of time must however be long enough to permit transients produced on energizing a previous leg to be diminished to a sufficient level.

25   The method may further involve disconnecting the Y-connected load from the transient-limiting impedance after the third leg is energized. The Y-connected load may be disconnected from the transient-limiting impedance a period of time after the third leg is energized. The period of time may be greater than or equal to a time period associated with approximately one cycle of an AC waveform associated with
30   the three phase power system. The period of time may be greater than or equal to approximately 0.01 seconds. The period of time may be between approximately 0.01

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seconds and 1 second. In general, disconnecting the transient-limiting impedance from the Y-connected load can be initiated as soon as the transients produced on energizing the third leg have subsided to a sufficient level.

5   The method may further comprise connecting the neutral point of the Y-connected load directly to ground after the third leg is energized. The neutral point of the Y-connected load may be connected directly to ground a period of time after the third leg is energized. The period of time may be greater than or equal to a time period associated with approximately one cycle of an AC waveform associated with the three

10   phase power system. The period of time may be greater than or equal to approximately 0.01 seconds. The period of time may be between approximately 0.01 seconds and 1 second. In general, connecting the neutral point directly to ground can be initiated as soon as the transients produced on energizing the third leg have subsided to a sufficient level.

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In accordance with another aspect of the invention there is provided an energization transient limited three phase AC power system apparatus. The apparatus includes a three phase Y-connected load having a common neutral point and legs A, B and C associated with corresponding phases of the three-phase AC power system and

20   switches operable to connect respective corresponding phases of the three phase power system to the legs A, B and C of the Y-connected load. The apparatus further includes a switch controller operable to actuate the switches to energize respective legs of the load in an order determined by an energization sequence dependent upon a type of the load, the energization sequence defining first, second and third legs of

25   the legs A, B and C to be energized. The apparatus may further include a conduction path for current to flow between the common neutral point and ground while the first, second and third legs are being energized. The conduction path includes a transient-limiting impedance having an impedance value such that after the first leg is energized, an energization transient produced on energizing the second leg and an

30   energization transient produced on energizing the third leg are both approximately minimized.

The switches may include first, second and third switches associated with the first, second and third legs respectively.

5   The apparatus may further include a disconnect operable to disconnect the Y-connected load from the transient-limiting impedance after the third leg has been energized. The switch controller may be operable to control the disconnect. The switch controller may cause the disconnect to be actuated a period of time after the third leg is energized. The period of time may be greater than or equal to a time
10   period associated with approximately one cycle of an AC waveform associated with the three phase power system. The period of time may be greater than or equal to approximately 0.01 seconds. The period of time may be between approximately 0.01 seconds and 1 second.

15   The apparatus may further include a bypass switch operable to connect the neutral point directly to ground after the third leg is energized. The switch controller may be operable to control the bypass switch. The switch controller may cause the bypass switch to be closed a period of time after the third leg is energized. The period of time may be greater than or equal to a time period associated with approximately one cycle
20   of an AC waveform associated with the three phase power system. The period of time may be greater than or equal to approximately 0.01 seconds. The period of time may be between approximately 0.01 seconds and 1 second.

In accordance with another aspect of the invention, there is provided an energization
25   transient limited three phase AC power system apparatus. The apparatus includes a three phase Y-connected load having a common neutral point and legs A, B and C associated with corresponding phases of the three-phase AC power system. The apparatus further includes provisions for energizing respective legs of the load from the corresponding phases of the three phase AC power system, in an order
30   determined by a energization sequence dependent upon a type of the load, the energization sequence defining the first, second and third legs of the legs A, B and C

to be energized. The apparatus further includes a conduction path for current to flow between the common neutral point and ground while the first, second and third legs are being energized. The conduction path includes a transient-limiting impedance having an impedance value such that after the first leg is energized, an energization

5   transient produced on energizing the second leg and an energization transient produced on energizing the third leg are both approximately minimized.

The provisions for energizing may include switching provisions operable to connect respective corresponding phases of the three phase power system to the legs A, B

10   and C of the Y-connected load.

The switching provisions may include switches operable to connect the legs A, B and C of the Y-connected load to respective corresponding phases of the three phase power system and a switch controller operable to actuate the switches to energize

15   respective legs of the load in the energization sequence.

Apparatus and methods according to this invention are simple and cost-effective. Precise control of the switch closing instants when energizing each leg is not required thereby allowing less expensive switches or breakers and switching controllers. The

20   transient-limiting impedance can be left in the circuit after energization since it will not affect the normal operation of the power system. Where the transient-limiting impedance is bypassed or disconnected after energization, it will be appreciated that the rating of the bypass switch or disconnect can be relatively low since the transient-limiting impedance does not carry voltage or current when the energized system

25   enters a balanced steady state.

Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

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BRIEF DESCRIPTION OF THE DRAWINGS

In drawings which illustrate embodiments of the invention,

Figure **1**   is a schematic diagram of an apparatus according to a first embodiment of the invention;

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Figure **2**   is a graph illustrating inrush current/transient voltage versus transient-limiting impedance for each of three legs of a Y-connected load, for use in selecting an optimal transient-limiting impedance value;

10   Figure **3**   is a graph of open circuit voltage versus transient-limiting impedance for switches associated with second and third legs of the load to be energized for alternative use in determining an optimal transient-limiting impedance value;

15   Figure **4**   is an apparatus according to a second embodiment of the invention in which the Y-connected load is predominantly inductive;

Figure **5**   is an apparatus according to a third embodiment of the invention in which the Y-connected load is predominantly capacitive; and

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Figure **6**   is a schematic diagram of an apparatus according to fourth and fifth embodiments of the invention for use with grounded neutral and ungrounded neutral systems respectively.

25   **DETAILED DESCRIPTION**

Referring to Figure **1**, an energization transient limited three-phase AC power system apparatus is shown generally at **10**. The apparatus includes a three-phase Y-connected load **12** having a common neutral point **14** and legs A, B, and C connected to the common neutral point and associated with corresponding phases A, B and C of

30   a three-phase AC power system. The apparatus further includes switches **22**, **24** and **26** operable to connect respective legs of the Y-connected load **12** to respective

phases A, B and C of the three-phase power system. The switches **22**, **24** and **26** may include circuit breakers, for example.

5   The apparatus **10** further includes a switch controller **28** operable to actuate the switches **22**, **24** and **26** to energize respective legs of the load **12** in an order determined by an energization sequence dependent upon a type of the load. The energization sequence defines the first, second and third legs of legs A, B and C to be energized, in succession.

10   The switch controller **28** actuates the switches **22**, **24** and **26** to cause the second leg in the energization sequence to be energized a period of time after the first leg in the energization sequence is energized and causes the third leg in the energization sequence to be energized a period of time after the second leg is energized. This period of time may be greater than or equal to a time period associated with
15   approximately one cycle of an AC waveform associated with the three phase power system and in any event is long enough to permit any transients to settle such that a steady state condition is achieved. A suitable time period might be approximately **0.01** seconds, or between approximately **0.01** seconds and **1** second, for example.

20   The switch controller **28** employs different energization sequences that actuate the switches **22**, **24** and **26** in different sequences depending on the type of load **12**. In particular, for a predominantly inductive load, the switch controller **28** employs an inductive load energization sequence that actuates the switches **22**, **24**, **26** to energize the legs of the load in the order A, B, C. That is, the first switch to be actuated is switch
25   **22** associated with leg A. The second switch to be actuated is switch **24** associated with leg B and the third switch to be actuated is switch **26** associated with leg C. The order A, B, C includes the order B, C, A and C, A, B since the labels A, B and C are sequential but arbitrary.

30   Where the Y-connected load is a predominantly capacitive load, the switch controller **28** employs a capacitive load energization sequence that actuates switch **22**

associated with leg A, then switch **26** associated with leg C and then switch **24** associated with leg B to energize the legs in the order A, C, B. The order A, C, B includes the order C, B, A and B, A, C since the labels A, B, C are sequential but arbitrary.

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The apparatus **10** further comprises a conduction path shown generally at **30** that enables current to flow between the common neutral point **14** and ground **32** through a transient-limiting impedance **34** while the first, second and third legs of the applicable energization sequence are being energized. The transient-limiting impedance **34** has a value such that after the first leg of the sequence is energized, an energization transient produced on energizing the second leg of the sequence and an energization transient produced on energizing the third leg of the sequence are both approximately minimized or reduced to an acceptable level. For an inductive load, the second leg of the sequence to be energized would be leg B and the third leg to be energized would be leg C. For a capacitive load, the second leg of the sequence to be energized would be leg C and the third leg to be energized would be leg B.

The energization transient produced on energizing the second and third legs of the energization sequence is a voltage or current transient, depending upon whether the Y-connected load **12** is predominantly inductive or capacitive. Where the Y-connected load is predominantly inductive, the energization transient of interest for determining the transient-limiting impedance is current, whereas for a capacitive load, the energization transient of interest is voltage.

Figure **2** shows a plot of magnitude of inrush current/transient voltage versus transient-limiting impedance. In the case of an inductive load, the magnitude of inrush current is plotted against transient-limiting impedance. In the case of a capacitive load, the magnitude of transient voltage is plotted against transient-limiting impedance. Figure **2** shows a first curve **40** depicting magnitude of inrush current/transient voltage versus transient-limiting impedance for the first leg to be energized.

The curve **40** may be produced according to numerical simulation methods, for example. Effectively, the magnitude of the inrush current or transient voltage in the first leg to be energized is dependent upon the impedance of the leg itself and the impedance of the transient-limiting impedance **34** shown in Figure **1** and is thus a
5   relatively simple calculation independent of the remaining legs.

Figure **2** also shows a second curve **42** plotting magnitude of inrush current/transient voltage versus transient-limiting impedance for the second leg to be energized. The second curve **42** shows a current or transient voltage that initially decreases with
10   increasing transient-limiting impedance and then increases with increasing transient-limiting impedance. Figure **2** also shows a third curve **44** depicting magnitude of inrush current/transient voltage versus transient-limiting resistance for the third leg to be energized and shows an increasing inrush current or transient voltage in response to an increasing transient-limiting impedance.
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The inrush current through the first leg to be energized is independent of the impedance of the second and third legs, therefore a lowest transient-limiting impedance value for which the energization transient (inrush current or transient voltage) is approximately the equal for both the second and third legs to be energized
20   is a reasonable compromise to reduce inrush currents in all three legs. In the example shown in Figure **2**, a optimum impedance Zopt may be defined as the impedance corresponding to an intersection **46** of the second and third curves **42** and **44**. More succinctly, a fairly optimum transient-limiting impedance value may be selected as an impedance value approximately equal to an impedance value at which a curve
25   depicting transient magnitude versus transient-limiting impedance for the second leg to be energized intersects with a curve depicting magnitude versus transient-limiting impedance for the third leg to be energized. At typical power system frequencies of **60** Hz, for example, any transient-limiting impedance value within about –20% to +30% of the optimal impedance value calculated using the method shown in Figure **2** will
30   provide a significant reduction in energization transients.

As a practical matter, the use of the curves shown in Figure 2 is particularly well suited to numerical simulation techniques, but is difficult to verify in practice. A practical method of determining an approximate transient-limiting impedance 34 is to select an impedance value such that when the first and second switches defined by the

5   energization sequence are actuated and the corresponding legs of the load are energized, a minimum steady state open circuit voltage across the third switch is approximately equal to a minimum steady state open circuit voltage across the second switch when only the first leg is energized. Thus, an optimal transient-limiting impedance value can be obtained by successively energizing the legs of the load 12 in

10   the appropriate energization sequence determined by the load type, with different impedances being used as the transient-limiting impedance 34, while measuring the open circuit voltage across the second and third switches at appropriate times during the energization sequence and selecting an impedance which produces the least difference in voltage between the open circuit voltage across the third switch when the

15   first and second legs are energized and the open circuit voltage across the second switch in the energization sequence when only the first leg 14 of the load 12 is energized. The impedance that produces the minimum same open circuit voltage across the second and third switches to be energized is an optimum transient-limiting impedance. An appropriate time for measuring the open circuit voltage across the

20   second switch is just before actuating the second switch and an appropriate time for measuring the open circuit voltage across the third switch is just before actuating the third switch.

Referring to Figure 3, the voltages across the second and third switches actuated in

25   the energization sequence may be plotted versus transient-limiting impedance, thereby producing a first open circuit voltage curve 50 representing open circuit voltage across the second switch to be actuated in the energization sequence while the first leg 14 is energized and a second curve 52 representing open circuit voltage across the third switch to be actuated in the energization sequence while the first and

30   second legs 14 and 16 are energized. The voltage across the second switch to be actuated in the energization sequence initially decreases with increasing transient-

limiting impedance and then increases. The voltage across the third switch to be actuated in the energization sequence increases with increasing transient-limiting impedance. A point of intersection **54** of the two curves **50** and **52** is associated with an optimal impedance value Zopt that reduces energization transients significantly. An

5 impedance within a range of –**20%** to +**30%** of this Zopt has been found to produce satisfactory results.

It has been found that the optimum transient-limiting impedance includes at least one of a resistive component and a reactive component and one or both of these may be

10 determined as a function of an open circuit reactance of the load.

Referring to Figure **4**, an apparatus having an inductive Y-connected load is shown generally at **60**. The inductive Y-connected load is shown at **62** and includes a neutral point **64** and predominantly inductive legs A, B and C connected to switches **82, 84**

15 and **86**, respectively, controlled by a switch controller **88**. The inductive Y-connected load **62** may be a reactor or transformer load, for example. Where the load **62** is a transformer load, the Y-connection may refer to that of a primary winding of the transformer and such transformer may have a delta-connected secondary winding. Generally, if the transformer has a three-limb core structure, any secondary winding

20 connection will be suitable and energization transients will be reduced accordingly. In general, a delta connection provides electrical coupling and a three-limb core structure provides magnetic coupling among the three legs of the load. The coupling, either electrical or magnetic, is important in reducing the inrush current. For transformers with either form of coupling, the maximum reduction of inrush current can be as high

25 as **90%**. For transformers without coupling, the maximum reduction of inrush current may be only about **30%**.

It will be appreciated that each leg A, B and C of the Y-connected load has an open circuit reactance Xopen having a fixed value at the frequency (typically **50** or **60** Hz) of

30 the power system. In general, predominantly resistive transient-limiting impedances have been found to be best suited for reducing energization transients in inductive Y-

connected loads. For relatively small transformers with **120** volt Y-connected primary windings and delta-connected secondary windings with **30** KVA power ratings, for example, a transient-limiting impedance **74** having a resistance of approximately **0.085**Xopen provides about **90%** reduction in inrush current. In this embodiment, the

5 energization sequence is A, B, C.

For the embodiment shown in Figure **4**, a further simplified method to determine the optimum transient-limiting impedance may involve establishing analytical formulas for the two open circuit voltage versus transient limiting impedance curves shown in

10 Figure 3. The analytical formulas may be used to express the open circuit voltages as functions of the transient-limiting impedance and the load parameters such as Xopen. As an example, the open circuit voltages can be expressed with the following formulas for the inductive load type assuming the switching sequence is A, B and C:

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$$|V_{S2}| = E\sqrt{3 + X_{open}\frac{X_{open} + \sqrt{3}R_N}{R_N^2 + 4X_{open}^2/9}}$$

$$|V_{S3}| = E\sqrt{\frac{9R_N^2}{4R_N^2 + X_{open}^2/9}}$$

where

20
$|V_{s2}|$ is the open circuit voltage across the second switch in the applicable energization sequence after the first leg has been energized,

$|V_{s3}|$ is the open circuit voltage across the third switch in the applicable energization sequence after the first and second legs have been energized,

25
E is the phase to ground voltage of the supply power system,

R_N is the resistance value of the transient-limiting resistance, and

X_{open} is the (positive sequence) open circuit impedance of the load.

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The above equation is applicable for transformers with a delta-connected secondary winding or with a three-limb core structure. These transformers have a mutual coupling among the three phases. The intersection point of the two curves can be obtained by letting:

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$$|V_{S2}|=|V_{S3}|$$

The result is the formula to calculate the optimal R_N, Ropt=**0.085**Xopen, for transformers with a delta-connected secondary winding or with a three-limb core

10 structure.

A similar set of formulas can be derived for the capacitive loads and other inductive loads.

15 Referring to Figure **5**, an apparatus **100** is shown having a capacitive Y-connected load **102** having a neutral point **104** and predominantly capacitive legs A, B, C, respectively, connected to switches **112, 114** and **116** controlled by a switch controller **118**. In this embodiment, each leg A, B, C, of the capacitive Y-connected load **102** has an open circuit capacitive reactance $X_c=\dfrac{1}{\omega C}$ where C is the capacitance of a given leg

20 (which may include a capacitor bank) and ω is the angular frequency of the power supply system. In this embodiment, a transient-limiting impedance **120** includes a resistor **122** and an inductor **124** connected in series between the neutral point **104** and ground **32**. In this embodiment, the resistor value may be calculated as a first proportion of the capacitive reactance X_c, such as **0.085**X_c and the inductance may be

25 calculated as a second proportion of the capacitive reactance, for example, 1/3X_c. The corresponding reduction of transient voltage is about **40%**. The reduced effect of limiting transient voltage in the capacitive load case is due to the fact that there is no electrical or magnetic coupling among the three phases of a capacitive load. In this embodiment, the energization sequence is A, C, B.

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Referring to Figure **6**, an apparatus according to an alternative embodiment of the invention is shown generally at **130** and includes the apparatus **10** shown in Figure **1** with a bypass switch **132** connected across the transient-limiting impedance **34** and controlled by the switch controller **28**. In this embodiment, the switch controller **28**

5   functions such that the bypass switch **132** is open during energization of the load **12** and after the load has been energized by actuating the switches **22**, **24** and **26** in the appropriate order for the type of load, the bypass switch **132** is closed so that a direct connection is made between the neutral point **14** and ground **32**. The switch controller **28** actuates the bypass switch **132** a period of time after the third leg of the

10   energization sequence is energized. This period of time may be greater than or equal to a time period associated with approximately one cycle of an AC waveform associated with the three phase power system. A suitable time period might be approximately **0.01** seconds, or between approximately **0.01** seconds and **1** second, for example.

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Alternatively, a disconnect **134**, such as a switch or circuit breaker, may be placed in series between the neutral point **14** and the transient-limiting impedance **34** and the bypass switch **132** is omitted. In this embodiment, the switch controller **28** controls the disconnect **134** such that it is closed when the load **12** is being energized and is

20   opened after the third leg is the energization sequence has been energized. This configuration is suitable for an ungrounded neutral system.

The switch controller **28** may actuate the disconnect **134** a period of time after the third leg is energized. This period of time may be greater than or equal to a time period

25   associated with approximately one cycle of an AC waveform associated with the three phase power system. A suitable time period might be approximately **0.01** seconds, or between approximately **0.01** seconds and **1** second, for example.

It will be appreciated that a separate switch controller (not shown) separate from

30   switch controller **28** may be used to control the bypass switch **132** or disconnect **134**, respectively.

While specific embodiments of the invention have been described and illustrated, such embodiments should be considered illustrative of the invention only and not as limiting the invention as construed in accordance with the accompanying claims.

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